1 up

NASA TECHNICAL TRANSLATION

NASA TT F-14407

EXPERIMENTS ON A PROGRAM OF WORLD MAGNETIC SURVEY

Sh. Sh. Dolginov, V.I. Nalivayko, A.V. Tyurmin and M.N. Chinchevoy

Translation of: "Eksperimenty po programme mirovoy magnitoy s"yemki"; Issledovaniya Kosmicheskogo Prostranstva (Study of Outer Space), "Nauka" Press, Moscow, 1965, pp. 606-614.

(NASA-TT-F-14407) EXPERIMENTS ON A PROGRAM OF WORLD MAGNETIC SURVEY S. Dolginov, et al (Techtran Corp.) Mar. 1972 15 p CSCL 08N

N72-27354

Unclas

G3/13 33988

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D. C. 20546 MARCH 1972

EXPERIMENTS ON A PROGRAM OF WORLD MAGNETIC SURVEY

Sh. Dolginov, V. I. Nalivaido, A. V. Tyurmin, and M. V. Chinchevoi

ABSTRACT: This article points out briefly the desirability of having more accurate maps of the distribution and intensity of the earth's magnetic field, mentioning that up until recently much of the earth's surface had not really been plotted. Plotting the magnetic field from satellites is very definitely considered the most expeditious way of getting this information.

Use of proton magnetometers is stated to be the method of choice for determining the magnetic field at any point, preferably from relatively low-flying satellites flying in substantially circular orbits. The mode of operation of such magnetometers is described briefly, and then the authors describe how these can be operated to give data in a satellite which can be either transmitted to an earth station or memorized. (The latter technique is deemed better).

Some of the results of past measurements which satellites are shown as graphs. Evidence is given to show that spurious signals resulting from unfavorable orientation or deceptive noise to signal ratio can be identified and rejected.

Finally, some of the anticipated future benefits to be attained by a systematic world survey of the magnetic field are indicated. In particular the hope is expressed that this may lead to a better understanding of the long-term trend of the earth's magnetic field.

1. World Magnetic Survey

In May, 1958, measurements were made for the first time of the magnetic /606* field of the earth and its nearby environments, at heights of 230-800 km above a vast region of the globe--the territory of the Soviet Union [1, 2]. A comparison of the measured values of the geomagnetic field with those calculated on the basis of magnetic charts of the territory of the Soviet Union made it possible to establish that they differed within a range of 0.1% [3].

---

* Numbers in the margin indicate pagination in the foreign text.

In 1959, measurements of the magnetic field were made in the height range 500-3500 km on the satellite Vanguard-3 [4] above individual regions of the USA, Latin America, and Australia. Comparison of the values measured on Vanguard-3 and those calculated on the basis of various variants of analytical representations of the geomagnetic field made it possible to establish also that they differed within a range of up to 1.5% [5]. The satellite measurements of the geomagnetic field mentioned above were made over comparatively well-studied regions of the globe. The greater part of the globe has been studied considerably more poorly, especially the world sea mass.

One must bear in mind that maps made up from detailed and reliable measurements after a certain time no longer reflect the true field distribution, since the magnetic field of the earth is undergoing slow-long-range changes. The most important features of these changes are a decrease in the overall magnetic field of the earth, and a systematic drift of the field to the west. Thus, in the last one hundred years the magnetic moment of the earth has decreased by 5%, and the magnetic pole of the dipole part of the field has been shifted along a parallel by 5° to the west.

The long-term trend of the magnetic field is a very complex and far from well-studied phenomenon. It is different in various regions of the globe, having varied with time in one and the same place, and depends on the level of magnetic and solar activity. In individual places, the long-term trend attains a magnitude of 150 γ/year [6]. One of the basic limitations in a study of the long-term trend is the low amount of study over the larger part of the globe. Over four-fifths of the earth's surface there have been no repeated measurements of the magnetic field. Large regions have not been studied with magnetic instruments. Moreover, a study of the principles of the long-term trend has immense importance for investigation of the internal structure of the globe and the nature and origin of the geomagnetic field; and also has great practical value, since it would make it possible to predict changes in the magnetic field over the earth's surface and operationally define magnetic maps more precisely.

The question of a world magnetic survey was first discussed at a session of the International Union of Geodesy and Geophysics in Toronto, in 1957, and /607 there was a more detailed discussion of this question in Moscow at the conference of the KSAZh in 1958. It was proposed to make a general magnetic survey by the various available methods and, consequently, on various levels from the earth's surface: by ground-level devices, aeromagnetometers, measurements on a nonmagnetic ship, by magnetometers towed by ships and set in nonmagnetic gondolas, and, finally, by survey from artificial earth satellites. The last method is the quickest. So far it makes possible solution of not all, but the principal problems of the world magnetic survey project. Measurements from satellites were particularly contemplated by the Soviet national program of the World magnetic survey.

2. Magnetic Survey from a Satellite

The possibility of carrying out a magnetic survey from a satellite is based primarily on the fact that, at heights which are minimally practicable for the reasonably long and safe existence of an artificial earth satellite, the geomagnetic field, which diminishes with height proportionally to the cube or higher powers of the distance from the center of the earth, maintains its main characteristic features. Regional intense anomalies of 300 - 400 km extent make a noticeable contribution to the magnetic field at a height of 250 - 300 km. Thus, according to the calculations of Ponomarova [7], a magnetic anomaly of 450 km extent whose intensity on the earth's surface attained a magnitude of 3000 γ had an intensity of about 200 γ at a height of 200 km.

Thanks to the difference in period of rotation of the satellite in its orbit and the period of rotation of the earth around its axis, with the aid of a satellite whose active lifetime is about 15 days it is possible to make a rather detailed survey of the globe. Actually, when the period of rotation of the satellite is about 90 minutes, each turn, on the assumption that the orbit is immovable with respect to the stars, will be located approximately 22.5° away from the next in the plane of the equator. Because of the nonsphericity of the earth, the satellite orbit will be shifted to the west by 4.5° per day at an inclination of 50°. Consequently, after five days the 22.5° spacing will be filled with turns having an interval of aobut 4.5°. After ten days the interval between turns in the plane of the equator is 2.2°. The turns spaced 4.8 days apart will have closely similar values of ϕ and λ. Thus, when there is an active lifetime of about 15 days, it appears possible to obtain sufficient information and repetitions of measurements at points have closely similar values of ϕ and λ. However, if the satellite flies at a comparatively small distance from the earth, the height of its flight over the surface will change rather rapidly, and repeated measurements at the very same points in space are practically impossible. Nevertheless, a long existence time would be desirable for more reliable study of the effect of external sources of the variable magnetic field of the earth. For further analysis of the data, an orbit close to circular is most convenient.

The problem of a world magnetic survey in one experiment can be solved when the orbit has an inclination of about 85° to the plane of the equator. At the indicated minimum active satellite existence time, the minimum number of readings per turn should rationally be equal to 180. When the inclination of the orbit to the plane of the equator is 49°, about 75% of the global surface is encompassed by the magnetic survey. Such conditions are present when small satellites of the "Cosmos" series are used. Thus, a survey from a satellite permits one to obtain a practically simultaneous picture of the intensity distribution of the magnetic field from homogeneous experimental data, uniformly distributed over the earth's surface.

3. Magnetometric Apparatus of the Satellites "Cosmos-26" and "Cosmos-49" /608

Proton magnetometers were used on small satellites of the "Cosmos" series. Measurement of a magnetic field by proton magnetometers reduces to measuring the frequency of free proton precession in the earth field being measured. The precession frequency of protons which possess a magnetic and mechanical moment is defined, as is well-known, by the Larmor relationship $\omega = \gamma_p H$, where γ_p is the gyromagnetic ratio, and H is the intensity of the field being measured.

In 1954, Packard and Varian [8] described a convenient method of observing free nuclear precession which permitted measuring weak magnetic fields with high accuracy: on a sample--a liquid with a large proton content (water and alcohol) which is present in the magnetic field to be measured, H--is applied, for a short time, an auxiliary polarization field, H_o (of the order of 100 oersteds) at an angle of 90° to the measured field H. Under the action of the field H_o, the sample acquires a macroscopic magnetization whose intensity will be given by $I_n = \chi_n H_o$, where χ_n is the nuclear succeptibility. After the field H_o if shut off, the macroscopic magnetic moment begins to precess freely around the field H with a frequency $\omega = \gamma_p H$. The magnitude of the macroscopic moment gradually diminishes. The relaxation time is about 3 seconds. This time is enough to measure the frequency of the voltage induced by the precessing moment of the sample in the signal coil of a pick-up (this is the excitation coil), connected up now to an amplifier. The variable EMF induced in the coil will be given by $E = K\chi_n \gamma_p H_o H \sin^2 e^{t/T_2}$, where K is a constant which depends on the coil parameters, the filling coefficient, and contour quality; θ is the angle between field H and H_o; and t is the time from the moment of shutting off the field H_o; and T_2 is the relaxation time.

The nuclear precession method has a number of remarkable properties:

1) measurement of a field reduces to measuring a frequency;

2) magnetometer readings are given in absolute measure;

3) the pick-up and channels which form the signal are free in principle from zero to creep;

4) results of measurements when the pick-up is immobile do not depend on the orientation of the pick-up in the field being measured;

5) the accuracy of measurement is determined only by the accuracy of the frequency meter and the ratio of signal to noise.

The following difficulties arise in measurements on a revolving object.

1) In rotation of the coil together with the object at an angular velocity $\dot{\varphi}$ around an axis perpendicular to the coil axis, the field H will be measured with an error $\Delta H = 3.7\dot{\varphi}$, where ΔH is expressed in gammas and $\dot{\varphi}$ is expressed in deg sec^{-1}.

2. Although the frequency of precission does not depend on orientation, the magnitude of the signal is proportional to $\sin^2\theta$, and when θ is small, the signal can be close to zero.

A proton magnetometer, as is well-known, was set up on the satellite Vanguard-3 [4]. On the satellite were set up only the blocks which formed and amplified the nuclear precession signal. The magnetometer performed 50 magnetic field measurements per day. The nuclear precession signal modulated the transmitter carrier. After receipt of the signal by the earth station, it was carefully refined by narrow-wave filters and was measured by accurate frequency meters. Thus, this instrument made it possible to perform measurements only in the zone of direct satellite visibility, in regions of a limited number of earth stations. Since the frequency of free nuclear precession in the range of fields being measured varies in the range 850 - 2100 Hz, measurement of the field over the whole orbit with a typical memory device /609 is possible only when the frequency of free proton precession is measured onboard and results of measurements are memorized in the form of a coded number.

Reliable onboard frequency meter operation is possible at a favorable signal to noise ratio. A favorable signal/noise ratio in a proton magnetometer is attained at a narrow band in the signal-forming channel. However, for the magnetometer to operate throughout the whole orbit, this channel should be a rather wide-band one. This contradiction can be solved if one uses an instrument with an automatic range switcher.

Among the different variants of such swithcing, preference was given to the magnetometer variant in which range retuning was performed by a logic scheme which analyzed the nuclear precession signal (suggested by V. I. Nalivaiko). In this variant, the optimum signal was to be sought by mechanical switching during the first session of measurements. The optimum position was memorized, and later on a change in range was to be carried out by switching onto one range in one direction or another. This idea of a self-adjusting magnetometer was arranged for in the instrument construction. Moreover, the construction was based on the schematic solutions of the PM-5 portable high-accuracy proton magnetometer. In the PM-5 magnetometer, the measurement range was changed by manual switching. Precession frequency was measured by an accurate frequency meter, which was a part of the magnetometer.

In the process of development, a more rational variant was proposed. In this variant, the search for the optimum signal was performed during each cycle of pick-up polarization, which ensured independence of each discrete field measurement. This circumstance is important, because in measurements on unoriented objects, the nuclear precession signal can be small or equal to zero at small angles of the pick-up axis to the field direction. A limitation of this method is the fact that a part of the useful signal is used up each time to carry out the search. However, this limitation could be overcome, and the advantages of the method were obvious. This method was suggested by M. M. Chinchev.

This principle was used in the magnetometer having the designation PM-4. In the course of part of the free nuclear precession period, the instrument automatically seeks the optimum signal, analyzes it, and, if the signal is large enough, stops the search and gives a solution for the frequency measurement. The optimum position is memorized thereupon, and in the future the frequency search is performed from this state. The measured frequency at the optimum signal is memorized in eight-channel code in the channels of the memory device of a radiotelemetric system.

The stated sequency of metrological operations is ensured by the functional elements of the PM-4 magnetometer block scheme, as shown in Figure 1. By external command the instrument switches on the polarization current for 2 seconds, after which it turns on the pick-up coil in the amplifier input. Search for the optimum signal is started--the whole range of measurement is laid out in 11 sub-ranges. An electronic commutator carries out alternate switching-on of these. When the commutator comes to a sub-range where there is a precession signal, the latter is amplified to a value sufficient to stop the electronic commutator with the aid of a search-stopping scheme. When the frequency search scheme carries out an interrogation of the sub-ranges and detects a signal in one of them, the search is stopped, but the measurement can be carried out only after a reading of 32 nuclear precession periods from the amplifier output. This makes it possible to distinguish the signal /610 from the noise. In the case of noise, the recalculation scheme is not fulfilled, and the search will be continued. When a signal is present in one of the sub-ranges, fulfilling of the detector recalculating scheme mandatorily takes place, the search is stopped, and the frequency meter input is opened. When the search is stopped, the number of the sub-range in which the signal was detected is memorized. In the succeeding cycle of measurement, the search begins from this sub-range. The frequency meter carries out a frequency measurement and its memorization in a binary calculation system. The recorded number, coded by stepwise voltage from 0 to 6 volts, is fed into the six channels of a telemetric system.

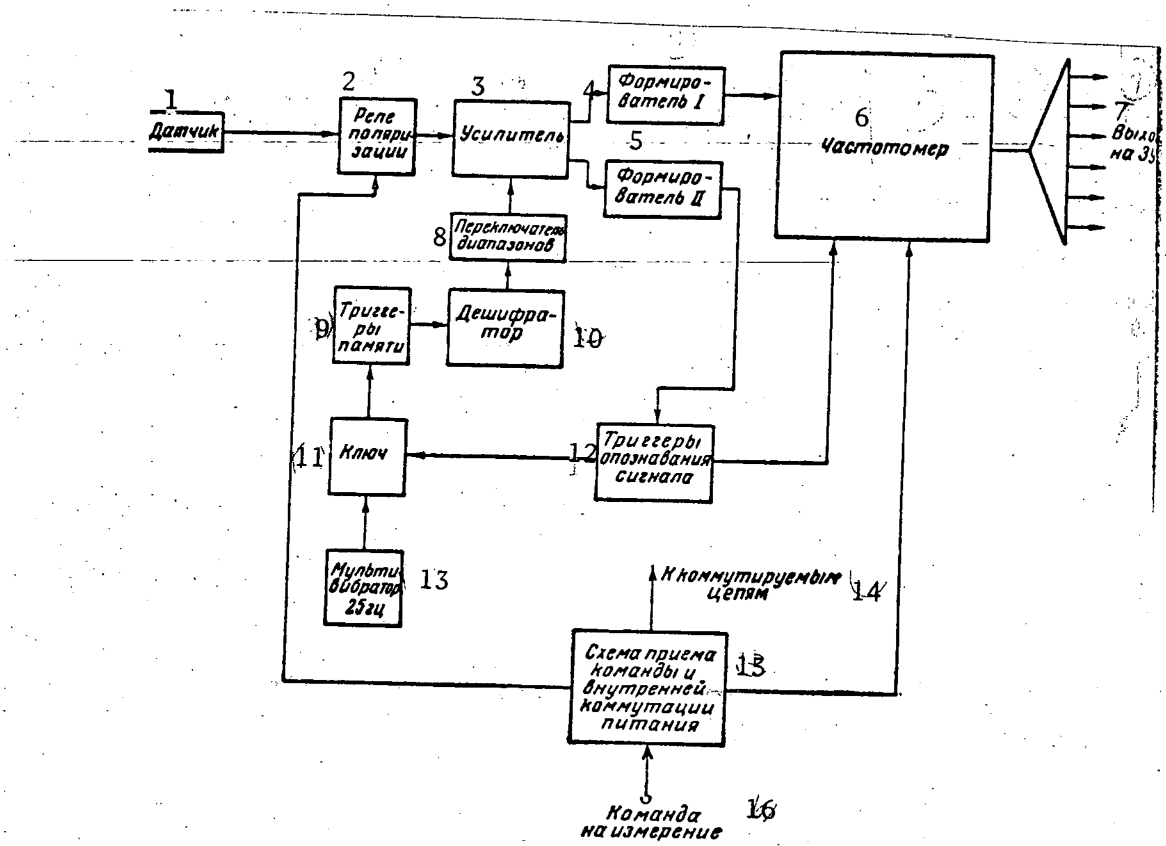

Figure 1. Block-scheme of PM-4 proton magnetometer.
Key: 1) Pick-up; 2) Polarization Relay; 3) Amplifier; 4) Shaper I; 5) Shaper II; 6) Frequency Meter; 7) Output to [Translator's note; illegible]; 8) Range Switcher; 9) Memory Triggers; 10) Decoder; 11) Switch; 12) Signal Identification Triggers; 13) 25 Hz Multivibrator; 14) To Commutatable networks; 15) Scheme of Command Receiver and Internal Supply Commutation; 16) Command for Measurement.

On the "Cosmos" satellites two magnetometers were set up, whose pick-ups were oriented at an angle of 90°. The instruments were switched on alternately from an accurate time-program device at 32-second intervals. Time tabs made it possible to tie in flight readings from each instrument to absolute time. The magnetometric pick-ups were removed from the center of the satellite, which contained magnetic parts, by a space of about 3.3 meters. The magnetic effect of the satellite at this distance was compensated for by a system of permanent magnets which created fairly homogeneous filed in the places where the pick-ups were located. Studies of a small series of PM-4 instruments in an observatory under conditions of an applied unknown field of an annular system showed that the accuracy of magnetometer measurement was 2-3 γ. Although at signal to noise ratios below the threshold value the frequency meter was closed and measurements were unlikely, nevertheless readings of lower accuracy were not excluded when the signals were weak. The detection and rejection of poor readings is possible, since they are ~~rather rare and lead to large gradients in values of the geomagnetic field,~~ which should not have been expected at large altitudes.

Measures were adopted so that when the satellite was separated from the carrier it would not acquire large angular velocities, which lead, as has been mentioned above, to errors in measuring nuclear precession frequency.

Information About the Magnetic Field and Plans for Scientific Treatment of Data /614

In the period from March 30, 1964 and from October 24 to November 6, 1964, measurements of the earth's magnetic field were made in a width band of ±49° from the equator, in a height range of 270-403 km ("Cosmos-26") and in the height range 270 = 490 km ("Cosmos-49").

In Figure 2 we give a typical magnetogram of magnetic field intensity along the trajectory of a single turn of the satellite "Cosmos-49". Readings of the PM-4-2 magnetometer are plotted as crosses; those of the PM-4-1, by points. Moments when the magnetometer was not giving information during unfavorable orientation are marked by points and crosses on the time axis. Cases of unauthentic readings are also evident on the magnetogram. They differ sharply from normal readings. In Figure 3 we give a chart of the magnetic coverage from the sputnik "Cosmos-26"; in Figure 4, a similar chart for the sputnik "Cosmos-49". At each point denoted on the chart, measurements were obtained for the scalar magnitude of the intensity of the earth's magnetic field.

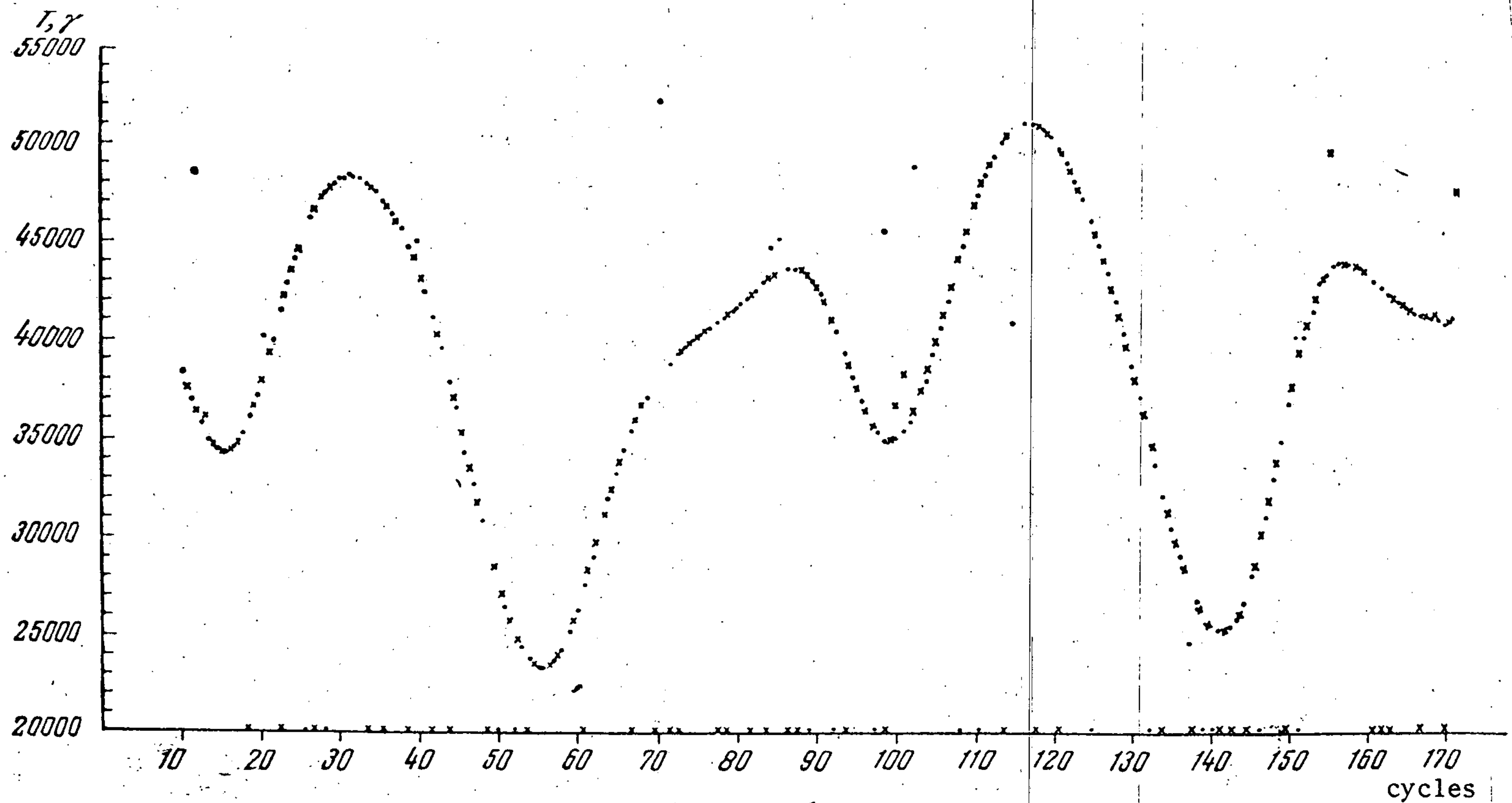

Figure 2. Typical magnetogram obtained from satellite "Cosmos-49". The crosses and points laid off on the time axis denote "forbidden" readings, when, due to unfavorable orientation, the signal to noise ratio was low and the frequency measurements. Spurious readings are also visible, which are easily distinguished from authentic ones.

/611

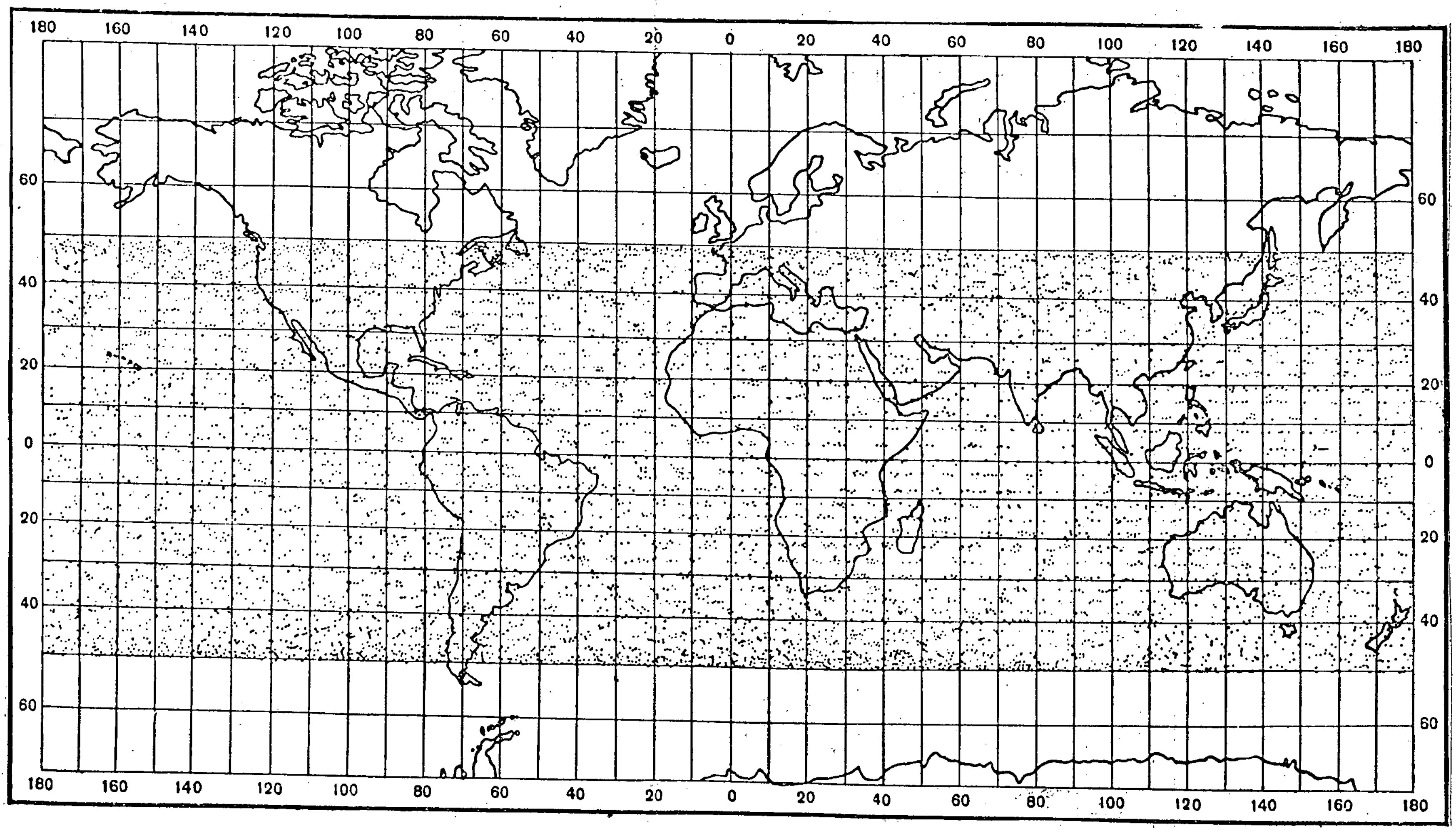

Figure 3. Chart of magnetic coverage in height range 270 - 404 km.

/612

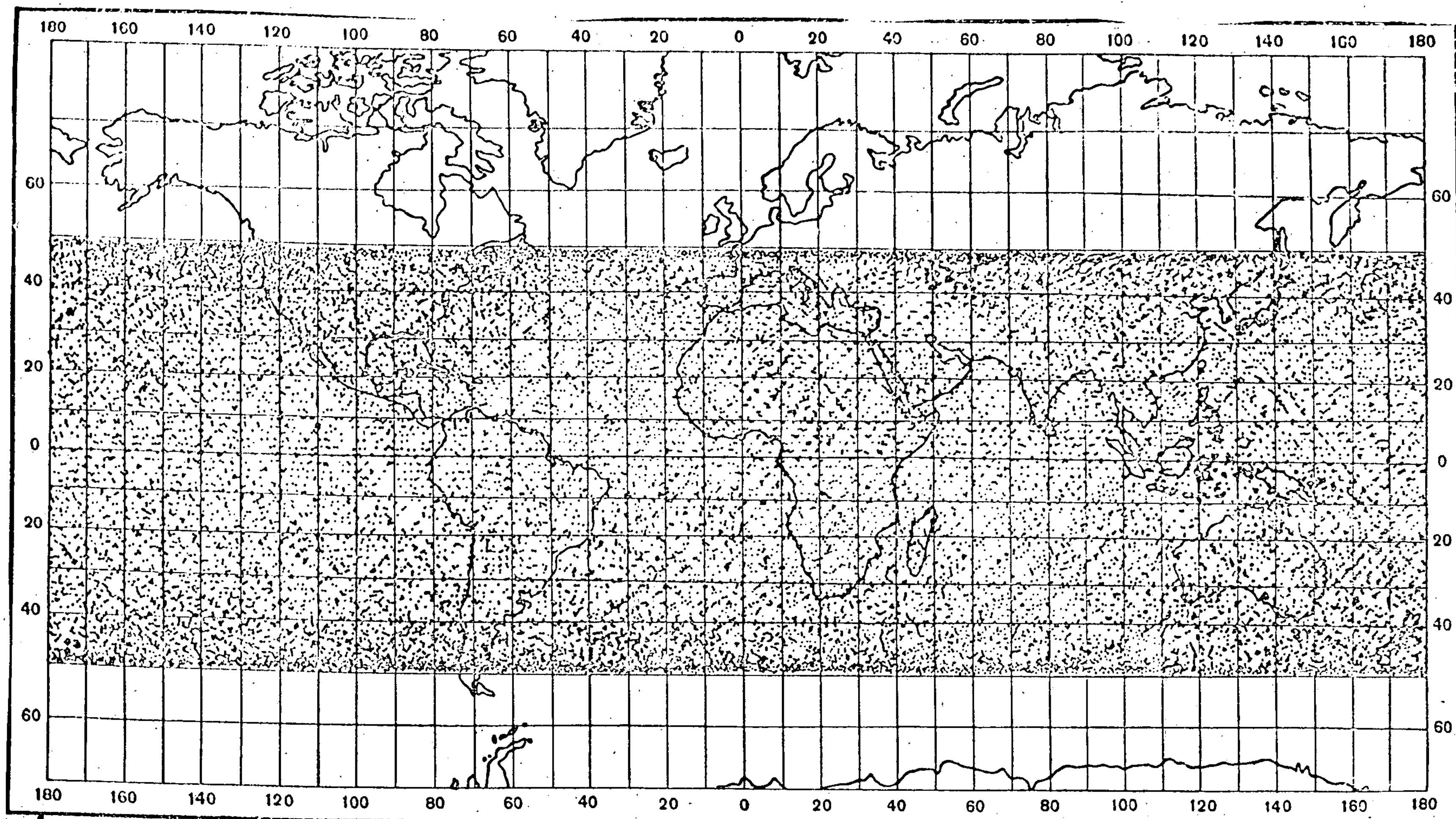

Figure 4. Chart of magnetic coverage in height range 270 - 490 km.

/613

The experimental material obtained permits carrying out scientific investigations in the following directions. /614

1. Study of the structure of the geomagnetic field of the earth; refining the coefficients of the guass series which represents the geomagnetic field analytically.

2. Determination of the long-term course of the geomagnetic field by comparing the coefficient of the guass series with the corresponding coefficients of other epochs. Foundation of an absolute network for study of the global long-term trend in the future.

3. Construction of the residual field (measured field minus dipole field) for a height of 350 km, and comparison of this with anomalies in the gravitational field as determined by use of satellites.

4. Study of the effects of a variable field in the ionosphere.

The authors feel it their pleasant duty to express their sincere thanks to G. N. Zlotin, I. N. Kiknadze, R. É. Brodskaya, A. R. Freidin, R. D. Kuznetsova, I. P. Ivchenko, A. V. Klimovskii, N. Yu. Protsenko, V. N. Fursenko, N. V. Chistovaya, M. N. Yakushenko, T. D. Grishina, and A. K. Nazarova for their participation in primary treatment of the experimental data. They also take this opportunity to express their thanks to the personnel and organizations who have assisted us in carrying out the experimental work.

REFERENCES

1. Sh. Sh. Dolginov, L. N. Zhuglov, and N. V. Pushkov, "Artificial Earth Satellites", *"Iskusstvennyye Sputniki Zemli"*, No. 2, Press of Akad. Nauk SSSR, pp. 50, 1958.
2. Sh. Sh. Dolginov, L. N. Zhuglov, and V. A. Senyutin, Ibid., Press of Akad. Nauk SSSR, No. 4, pp. 135, 1960.
3. Sh. Sh. Dolginov, L. N. Zhuglov, N. V. Pushkov, L. O. Tyurmina, and I. V. Frazinov, Geomagnetism i Aéronomiva, 1960.
4. F. P. Heppner et. al., Space Res., Vol. 1, pp. 982, 1960.
5. J. C. Cain, J. R. Shapiro, J. D. Stolarik, and J. Heppner, J. Geophys. Res., Vol. 67, pp. 5055, 1962.
6. V. P. Orlov, Geomagnetizm i Aéronomiya, Vol. 1, No. 2, 1961.
7. I. A. Povomareva, "Report on All-Union Conference on Geomagnetism and Earth Currents", *"Doklad Na Obshchesoyuznom Soveshchanii po Geomagnetiamy I Zemnym Tokam"*, Moscow, April 13, 1965.
8. M. Packard and R. Varian, Phys. Rev., Vol. 93, pp. 941, 1954.
9. J. Laurence et al., J. Geophys. Res., Vol. 61, Nc, 1956.

Translated for the National Aeronautics and Space Administration under contract No. NASw-2037 by Techtran Corporation, P. O. Box 729, Glen Burnie, Maryland 21061, Translated by: J. K. Lawson Jr., Ph.D